Changes in Water Quality Parameters and Fish Usage of Backwaters During Fluctuating vs. Short-Term Steady Flows in the Colorado River, Grand Canyon

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Abstract

The changes in water quality of backwaters and their use by fishes during fluctuating vs. short-term steady flows were examined in the Colorado River, Grand Canyon, 25 - 31 May 1994. Temperature gauges were deployed in four backwaters in the vicinity of the confluence of the Colorado and Little Colorado Rivers. Thirteen backwaters were sampled for fish use. Temperature, dissolved oxygen, and pH fluctuated daily under both fluctuating and steady flow regimes. Mean mainchannel temperature was warmer under steady flows. Mean, minimum, maximum, and diel range of backwater temperatures were higher under steady flows. Mean and minimum dissolved oxygen were lower under steady flows. Specific conductance and pH did not vary between flow regimes. Catch-per-unit-effort in backwaters did not differ under either flow regime. These results indicate that steady flows will cause warming of the mainchannel Colorado River and its backwaters and changes in other water quality parameters. These changes may both positively and negatively affect fish populations directly and indirectly through their influence on primary and secondary productivity and the potential for an increase in parasite and disease prevalence. These factors should be more closely examined before implementation of a steady flow regime or other changes that might increase water temperature in the river.

Introduction

The flow of water in the Colorado River through Grand Canyon is predominantly regulated by hypolimnetic discharge from Glen Canyon Dam. The closure of Glen Canyon Dam, in 1963, turned a seasonally warm, muddy river into a consistently cold clear one, greatly affecting the biota of the river corridor, particularly the native fishes. Alteration of spawning and rearing habitat, blockage of migration, and introduced native species have extirpated four of the original eight native species (Minckley 1991; Table 1). Only four native species remain: humpback chub (*Gila cypha*), flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*Catostomus discobolus*), and speckled dace (*Rhinichthys osculus*).

Glen Canyon Dam is operated as a peaking power hydropower facility. From closure of the dam in 1963 through July 1991, discharge release patterns have fluctuated widely on a daily basis and there were no restrictions on ramping rates. Discharge peaked in the early afternoon and could reach 893 m^3/s (31,500 cfs). Low discharge, as low as 28 m^3/s (1,000 cfs) or 85 m^3/s (3,000 cfs), depending on the time of year, occurred during the early morning. On 1 August 1991, interim operations were implemented, restricting daily flow fluctuations to a maximum discharge of 567 m^3/s (20,000 cfs), and a minimum of 227 m^3/s (8,000 cfs) from 0700h to 1500h and 142 m^3/s (5,000 cfs) at night. Ramping rates were also restricted to 71 m^3/s (2,500 cfs) per hour up and 43 m^3/s (1,500 cfs) per hour down.

Backwaters have become increasingly important as rearing areas for native fishes in the Colorado River system (Holden 1978; Valdez and Clemmer 1982; Carter et al. 1985; Maddux et al. 1987) due to changes in habitat caused by dams, particularly decreased water temperature. Backwaters are quiet pockets of water connected to the mainchannel (but with greatly reduced or no flow) and are formed in areas of eddies where scouring occurs under higher flows. As water levels drop, a reattachment sand bar is exposed, partially isolating the eddy return channel and forming the backwater (Rubin et al. 1990). Not only do backwaters provide calm, sheltered water, they are also warmer and contain greater densities of aquatic invertebrates than the mainchannel (Cole and Kubly 1976; AGFD unpublished). However, fluctuations in dam releases cause inundation and/or dewatering of backwaters, reducing their ability to support larval and juvenile fish (Kennedy 1979).

In an effort to improve habitat for native fish, a regimen of steady releases from Glen Canyon Dam has been proposed (U.S. Fish and Wildlife Service 1995). Stabilized river levels would prevent the daily loss and creation of backwaters. This diel cycle forces juvenile fish to move into or out of backwaters each day. Interrupting this cycle could improve conditions for juvenile fishes. Jourdonnais and Hauer (1993) speculated that forced movement, caused by alterations in river discharge may increase predation on juvenile fish. It is also likely that backwaters, under steady flow conditions, would support increased planktonic and benthic invertebrate communities as a result of increased temperature and decreased daily flushing (Kennedy 1979). A dramatic increase in benthic invertebrate populations has been shown in backwaters sampled under reduced fluctuations (AGFD unpublished) when compared to samples collected under flow regimes designed to maximize power production (Cole and Kubly 1976; Haury 1986, 1988). Conversely, turbidity, which is used as cover by native fishes (Valdez and Ryel 1995; AGFD unpublished), will likely decrease under steady flows. This would make backwaters and other nearshore areas less hospitable to larval and juvenile native fishes.

This study was conducted to examine differences in diel temperature changes in backwaters and the mainchannel during fluctuating vs. steady flows in the Colorado River, Grand Canyon. In a single backwater, pH, specific conductance, and dissolved oxygen were also monitored. Additionally, the use of backwaters and their associated mainchannel beachface habitats by fish during fluctuating and steady flows was examined. Changes in turbidity were also monitored at fish sampling sites. This report will provide initial data concerning the effect of steady flows on larval and juvenile native fishes and their habitat.

Study Area

This study was conducted on the Colorado River, in Grand Canyon National Park, near the confluence of the Colorado and Little Colorado (LCR) Rivers (RK 99; RK = river kilometers below Lee's Ferry). The reach between Kwagunt Rapid (RK 90.1) and Lava Chuar Rapid (RK 105.4) was explored for suitable backwaters. This reach is important because all four remaining native fish species reproduce in the LCR and rear in the mainstem Colorado River in this area (AGFD 1993). Larvae and juveniles of all species have been captured in the mainstem Colorado River downstream from the LCR and all except bluehead suckers are commonly captured upstream (AGFD 1993).

The backwaters monitored during this study varied in many physical charateristics which may affect warming and their chemical characteristics. These included: surface area, depth, mouth dimensions, amount of algae and/or aquatic vegetation, and exposure to solar radiation. Two backwaters, RK 94.6 L and RK 97.8 L, were well established, judging by the presence of aquatic, emergent, and terrestrial vegetation in and around them. The remaining two backwaters, RK 95.9L and RK 102.5 R, were bounded by clean sand bars and were probably more ephemeral.

The backwater at RK 94.6 L was long, wide, and mostly shallow (<1 m) and its size varied greatly with water elevation. The foot (terminal end) of this site remains a backwater except under high discharges ($\geq$510 m^3/s = 18,000 cfs), not seen during this study, which would inundate the site. Its mouth was wide and deep (>1 m) and its location and dimensions varied greatly. This backwater contained a dense mat of aquatic macrophytes, including *Potamogeton* and *Anachris* with *Equisetum* and *Typha* along its sides.

The backwater at 95.9 L was very small, narrow, and shallow. Its mouth was also shallow and narrow and the size of this backwater did not vary greatly with river elevation. This site would be inundated by flows barely exceeding those seen during this study. Due to its location partially under an overhanging ledge and the fact that the river there flowed north to south, this backwater received the least solar radiation of all of those studied. The only aquatic vegetation in this backwater was some *Cladophora* that had drifted in.

The backwater at RK 97.8 L was wide with both deep and shallow sections. The mouth was wide, but very shallow. This site would also require flows $\geq$510 m^3/s for inundation. This site was also very exposed to solar radiation and contained much aquatic vegetation, including *Potamogeton* and *Equisetum* in the shallow areas and *Cladophora* in the deeper areas.

The backwater at RK 102.5 R was wide and shallow with two arms. Its mouth was wide and deep. It was fairly well exposed to solar radiation, but contained no aquatic vegetation except some *Cladophora* that had drifted in.

Methods

Backwaters on the Colorado River, Grand Canyon, between Kwagunt Rapid and Lava Chuar Rapid were sampled during a period of four days of fluctuating flows, 25 - 28 May 1994, and two and one-half days of steady flows, 29 - 31 May 1994. Fluctuating flows ranged from 221 m^3/s (7,800 cfs) to 374 m^3/s (13,200 cfs) while steady flows were approximately 233 m^3/s (8,200 cfs). Steady releases from Glen Canyon Dam began at approximately 0600 h 28 May and reached the confluence of the Colorado and Little Colorado Rivers at approximately 0000 h on 29 May. Sampling was completed on 31 May when fluctuations resumed with a decrease in discharge at approximately 1500 h followed by an increase at approximately 2200 h.

Four backwaters, RK 94.6L, 95.9L, 97.8L, and 102.5R (note: 'L' and 'R' denote side of river when facing downstream), were selected based on the likelihood that they would persist under both flow regimes. Temperature gauges were placed in these backwaters on 24 May 1994. Mainchannel temperature and discharge data were obtained from the U.S. Geological Survey gauge on the Colorado River at RK 98.3 R, above the mouth of the LCR. In addition, a single Hydrolab DataSonde II (sonde) was placed in a backwater (RK 97.8L) to record changes in temperature, pH, specific conductance (conductivity), and dissolved oxygen. All instruments were set to record from 25 May - 1 June at 30 minute intervals. Differences in diel mean, minimum, and maximum temperature (°C), dissolved oxygen (mg/L), pH, and conductivity (µS/cm) between steady vs. fluctuating river discharge were tested using paired t-tests. The sequential Bonferroni test (Rice 1989) was used to determine the significance of differences at an overall $\alpha \leq 0.05$.

Fish populations were sampled by seining (30' x 6' with a 6' x 6' x 6' bag; 3/16" mesh wings; 1/8" mesh bag) in all available backwaters and their associated mainchannel beachfaces under each flow regime by a single seine pass. Sites were sampled only once daily, during daylight hours. Ambient air and mainchannel and backwater temperature and turbidity, time, flow stage, ambient light, maximum depth, effort (m^2 seined), and sonde or temperature gauge depth (if present in that backwater) were recorded during each sampling period. Differences in variables between steady and fluctuating river flows were tested using paired t-tests. The sequential Bonferroni test (Rice 1989) was used to determine the significance of differences at an overall $\alpha \leq 0.05$. Additionally, an index of catch-per-unit-effort (CPUE = # fish caught / 100 m^2 seined) was calculated for comparisons of catch between steady vs. fluctuating flows for each species and for total catch by ANOVA (α=0.05). Relationships between backwater CPUE for each species and total catch vs. water temperature, air temperature, and turbidity were tested with three-way ANOVA (α=0.05). Only two fish were caught in mainchannel seine hauls. Therefore, no analyses were conducted on mainchannel catches.

Results

Thirteen backwaters were sampled during the experimental period (Table 2). Six were present only under fluctuating flows (higher river discharge), two were present only under the lower discharge of steady flows and five were present under both fluctuating and steady flows.

The size and depth of the backwaters containing temperature gauges also varied under the two different flow regimes. Under fluctuating flows, maximum depth of backwaters changed as much as 63 cm, length as much as 6 m, and width as much as 3 m (Table 3). Under steady flows, maximum depth, length, and/or width increased over those dimensions recorded under steady flows. No changes were seen during steady flows since water elevation did not change.

Habitat Data

Water temperatures in both the mainchannel and backwaters had regular diel fluctuations under both fluctuating and steady flow regimes (Figure 1). Maximum temperatures occurred in the afternoon and minimum temperatures in the early morning hours.

In the mainchannel, mean temperature was 8.36°C under fluctuating flows but was significantly higher ($P=0.0020$ $\alpha=0.0100$) at 8.92°C under steady flows (Table 4). Mean daily minimum temperature, maximum temperature, and diel temperature range were not significantly different in the mainchannel under either flow regime ($P\geq0.0305$, $\alpha\geq0.0167$).

In backwaters daily mean, minimum, and maximum temperatures, and diel temperature range were significantly warmer under steady vs. fluctuating flows ($P\leq0.0046$ $\alpha\geq0.0063$). Daily mean temperature under fluctuating flows was 11.97°C and increased to 14.53°C under steady flows. Mean daily minimum temperature increased to 11.50°C, under steady flows, from 10.54°C, under fluctuating flows. Mean daily maximum backwater temperature under steady flows was 18.66°C but only 14.41°C under fluctuating flows. The mean diel temperature range was only 2.72°C under fluctuating flows but increased to 5.61°C under steady flows.

Daily mean and daily maximum water temperatures were significantly higher ($P\leq0.0040$) under steady flows in the monitored backwaters at 94.6L, 97.8L, and 102.5L, but not significantly different at 95.9L ($P=0.0104$, $\alpha\geq0.0100$). Daily minimum water temperature significantly increased ($P=0.0060$) from 10.80°C to 12.30°C in the backwater at 102.5R, but not at any other site ($P\geq0.0241$, $\alpha\geq0.0100$).

Additional data were collected from the backwater at RK 97.8L using a DataSonde (Figure 2). Mean temperature under fluctuating flows was 11.59°C and increased significantly ($P=0.0040$) to 13.90°C under steady flows. Mean maximum temperature under fluctuating flows (12.67°C) was also significantly colder ($P=0.0022$) than under steady flows (16.48°C). Mean minimum temperature under fluctuating flows was 10.72°C but was not significantly lower ($P=0.0241$, $\alpha\geq0.0063$) than under steady flows (12.05°C). Mean diel temperature range also was not significantly higher ($P=0.0134$, $\alpha\geq0.0042$) under steady flows (4.43°C) than under fluctuating flows (1.95°C).

pH levels showed regular diel variations under both fluctuating and steady flow regimes with maximum pH occurring in the afternoon and minimum in early morning. Mean, maximum, and diel range of pH were higher under steady than fluctuating flows, while mean minimum pH level was lower under steady flows. However, neither mean, mean minimum, mean maximum, nor mean diel range of pH were significantly different between flow regimes ($P \leq 0.0093$, $\alpha = 0.0063$).

Dissolved oxygen (DO) also fluctuated daily under both flow regimes. Maximum DO levels occurred in late afternoon and the minimum occurred in early morning under both flow regimes. Mean DO level was significantly lower ($P = 0.0015$) under steady flows (10.04 mg/L) than fluctuating flows (10.80 mg/L). Mean minimum DO was 10.11 under fluctuating flows and decreased significantly ($P = 0.0015$) to 8.89 mg/L under steady flows. Mean maximum DO level decreased from 11.9 mg/L under fluctuating to 11.86 mg/L under steady flows, but was not significantly different ($P = 0.9216$). Diurnal DO range increased under steady flows (2.97 mg/L) from that seen under fluctuating flows (1.79 mg/L), but was also not a significant change ($P = 0.0309$, $\alpha = 0.0063$).

Conductivity in this backwater behaved differently between fluctuating and steady flows but mean, mean minimum, mean maximum, and diel range of conductivity did not differ significantly ($P \geq 0.0533$) between the two flow regimes. Conductivity had bimodal diel fluctuations under the fluctuating flow regime with the highest levels being recorded during periods of ascending and descending river discharge. The lowest levels were found during peak discharge with minor decreases during low discharge. Conductivity during steady flows did not show the regular, diel changes seen during fluctuating flows but the range of conductivity during steady flows was greater than during fluctuating flows. Under steady flows, conductivity steadily increased over approximately 30 hours, decreased over approximately 36 hours, and then increased with changes in water level as the fluctuating flow regime resumed.

Fish Collection Data

Thirty-seven fish collections were made at 13 sites. All four native species, bluehead sucker, flannelmouth sucker, humpback chub, and speckled dace, and two exotic species, fathead minnow (*Pimephales promelas*) and rainbow trout (*Oncorhynchus mykiss*), were caught (Table 5). No significant differences ($P \geq 0.3416$) were found for CPUE in backwaters between steady vs. fluctuating flows for any species. No significant differences were seen between CPUE for each species and total catch vs. habitat variables ($P \geq 0.1260$). Only two fish (both speckled dace) were caught in mainchannel beachface seine hauls. This was probably due to the extreme clarity of the water during this period. Therefore, no analyses were conducted on mainchannel catches.

Mean mainchannel water temperature at time of fish sampling during steady flows was 12.19°C, significantly higher (P=0.0009) than during fluctuating flows (10.47°C; Figure 3). Mean backwater temperature, at time of sampling, was 12.3°C under fluctuating flows and increased significantly (P=0.0318) to 14.92°C under steady flows.

The river was extremely clear during the entire study. Mean mainchannel turbidity at time of fish sampling decreased from 4.92 NTU to 2.80 NTU under fluctuating and steady flows (Figure 4), respectively, but did not change significantly (P=0.1420). During fluctuating flows mean backwater turbidity was 7.67 NTU and decreased to 5.10 NTU under steady flows, but also was not significantly different (P=0.2280).

Discussion

It is evident that a 64 hour regimen of steady flows caused an increase in water temperature in both backwaters and the mainchannel Colorado River during late May 1994. Dissolved oxygen, pH, and conductivity in the backwater at RK 97.8 were also affected. Turbidity, in the already clear river, did not change significantly under steady flows. The increase in size and depth of many backwaters under steady flows was due to increased exposure of the sandbar with decreased water elevations.

Backwater temperatures are largely influenced by ambient temperature, solar radiation, and mainchannel temperature. Under fluctuating flows, backwaters may warm, but daily flushing with mainchannel river water resets the backwater temperature to approximately that of the mainchannel. Under the steady flow regime, diel fluctuations in temperature were influenced by solar radiation and changes in ambient temperature with less influence from the mainchannel. With minimum ambient temperatures well above that of the mainchannel water and no surge of mainchannel water, backwaters held heat better under the steady flow regime than under fluctuating flows. Additionally, backwaters may warm further the next day, depending on ambient temperature and solar radiation. In all sites, except 94.6L, daily mean, minimum and maximum temperatures occurred on the last day of steady flows, and at 94.6L maximum temperature occurred on the last day, indicating an increase in temperature over time. The full potential for backwater warming was probably not reached during this short period of steady flows and these data are insufficient to estimate the limit of warming.

The diel timing of flow fluctuations near the LCR are such that temperature variation in backwaters should be maximized. During fluctuating flows, peak discharges reached the LCR gauge between 0600h and 0900h, with the remainder of the day under steady or decreasing discharges. This should permit these backwaters to warm considerably throughout the day due to little input of new, cold water from the mainchannel. In most other areas of the Colorado River, Grand Canyon, warming should occur to a lesser degree since the timing of high and low discharge occurs at different times of the day, reducing the potential for warming. If low discharge occurs in the early to mid-morning, warming of backwaters should be greatly diminished as they are filled with cold river water during daylight hours.

Backwater temperatures under fluctuating flows were not those preferred by native fish in the Grand Canyon. Humpback chub prefer water temperatures of 21 - 24.4°C (Bulkley et al. 1982) and other native Colorado River fishes probably have similar preferences. These preferred temperatures are far from the 7.6 - 9.6°C temperature range recorded in the mainchannel during this study under both fluctuating and steady flows. Even in the monitored backwaters the maximum temperature was 17.66°C under fluctuating flows. The mean backwater temperature under steady flows increased to 14.18°C from 11.91°C under fluctuating flows. However, under the steady flow regime diel mean temperatures in one backwater (94.6L) reached 17.31 - 18.07°C, nearing the preferred temperature range, and maximum temperatures reached 22.88 - 23.77°C, well within this preferred range. Also, temperature in most backwaters showed indications of increasing with each day of steady flows. Therefore, it appears that under a regime of steady flows, temperature in some backwaters may approach, attain, or even exceed the preferred temperature of native fishes, particularly during warmer months, in shallow areas of backwaters, and in warmer areas (lower reaches) of the Colorado River, Grand Canyon.

The amount of warming in the backwaters monitored in this study varied and was likely influenced by its location (accessibility to direct solar radiation), size of mouth, eddy flow patterns at the mouth, and surface area and volume of the backwater. The backwater at RK 94.6L warmed more than the other backwaters under both fluctuating and steady flow regimes, probably because of its long, shallow (~20 cm) foot that is exposed to solar warming for a large part of each day. Also, the length of this backwater probably protected it from the influence of mainchannel water under steady flows. Maximum temperature at this site was 17.66°C under fluctuating flows and reached 23.77°C under steady flows on 31 May 1994. The maximum temperature recorded in any other backwater was 13.79°C under fluctuating flows and 17.27°C under steady flows, both at RK 97.8L where the shallow (~25 cm) mouth may have reduced the intrusion of mainchannel water.

The backwaters at RK 102.5R and 95.9L warmed the least under the steady flow regime. RK 102.5R had a wide, deep mouth that would permit a large amount of mixing with the mainchannel. The backwater at 95.9L was small, partially under a low undercut bank and its relatively deep mouth allowed intrusion of mainchannel water from regular surges in the river and waves caused by passing motorboats.

Dissolved oxygen and pH at RK 97.8L maintained diel fluctuations under both flow regimes and mean and minimum dissolved oxygen levels significantly changed between flow regimes. These changes in DO were probably due to photosynthetic/respiratory activity by algae (Wetzel 1983). Dissolved oxygen, under steady flows, was highest during the late afternoon when O_2 produced by algal photosynthesis was greatest. However, daily mean and mean minimum DO decreased under steady flows as biological oxygen demand during the night used O_2 which was not replenished by the influx of new water that occurs under fluctuating flows. pH was also highest during the late afternoon, probably due to the use of CO_2 by algal photosynthesis. The continued diel increases observed in mean and mean maximum pH under steady flows was probably due to a loss of CO_2 to growing algae. Therefore, it appears that fluctuations in flow mediated the diel changes in DO in this backwater caused by diel cycles of photosynthesis and respiration. However, the limits of these changes under an extended period of steady flows cannot be predicted from the present data.

Patterns of change in conductivity under steady flows were markedly different from the continued diel patterns noted for pH and DO. Conductivity oscillated daily under fluctuating flows but not under steady flows. Under fluctuating flows the lowest conductivity levels in the backwater at RK 97.8L coincided with peak river discharge, whereas the highest conductivity levels coincided with low river discharge. However, under steady flows conductivity in the RK 97.8L backwater continued to increase for approximately 40 hours (24 hours into the steady flows) then began to decrease (30 µS/cm) over approximately 36 hours. This pattern is perplexing and I speculate that these changes in backwater conductivity may be due to the influence of water stored in banks and sand bars.

The source of dissolved salts in the Colorado River is predominantly from rocks (Gibbs 1970). Water stored in sand bars along the Colorado River have higher conductivity than that of the mainchannel (Parnell and Bennett 1994). The obsreved increase in conductivity was likely due to draining of water stored in the banks. As water elevation increases, banks are flooded, exposing rocky substrate to dissolution by river water. As water elevation decreases, water absorbed by the banks during high flows slowly drains back into the river bringing dissolved ions with it. Backwaters, being semi-isolated, largely retain this increased conductivity until the intrusion of mainchannel water, under fluctuating flows, dilutes these ions.

The observed decrease in conductivity under steady flows was probably due to less input of new ions and a gradual loss of ions to the mainchannel. First, flow of bankwater storage likely began to dissipate, reducing the input of new ions into the backwater. Secondly, some exchange of water with the mainchannel likely occurred to reduce the ion concentration. Backwaters are connected to the mainchannel and there is mixing of the waters at the mouth. Mixing is probably greatest during daylight as backwaters warm and convective currents probably form. Conductivity decreased rapidly during the daylight on 30 and 31 May. Conversely, conductivity decreased little as backwaters cooled and convective currents decreased during the night of 30 - 31 May. This mixing may have been sufficient to cause the decrease in conductivity. Also, settling of suspended particles, taking some ions with them, may have additionally reduced conductivity in this backwater. Turbidity measurements taken at the time of fish collections show a decrease in turbidity from 2.14 NTU at 0950h 30 May to 1.17

NTU at 1105h 31 May. The resumption of fluctuating flows began with a decrease in discharge, again causing conductivity to increase due to the introduction of additional water stored in the banks. Therefore, I speculate that conductivity in backwaters under longer-term steady flows will be maintained near that of the mainchannel.

CPUE did not vary between steady vs. fluctuating flows for any species or total catch. However, the period of these steady flows was short and was probably not of sufficient time for fish to discover these habitat changes and react to them. The time required to observe a response by fish to steady flows is expected to be longer than the three days monitored in this study. This response will be measured by changes in growth, survival, recruitment, and reproduction in each species. Extended periods of steady flow will be required for fish populations and growth rates to be altered. At a minimum, backwater usage under steady flows by larval and juvenile fish probably won't increase until food (zooplankton and benthic invertebrates) availability increases. Increases in numbers of these organisms will probably take at least a couple of weeks, depending on the amount of the increase in backwater temperature and the life cycle of the invertebrate species of concern.

It can be safely concluded that backwaters and the mainchannel (to a lesser extent) will warm under a steady flow regime. I now speculate on several ecological changes that may be expected to be caused by this warming and their effect on native fish populations. These changes may be positive and/or negative for native fish populations and include changes in: algal, invertebrate, and fish communities, and the possibility of an increase in the distribution and prevalence of diseases and parasites, particularly the Asian tapeworm (*Bothriocephalus acheilognathi*).

Algal and invertebrate communities in backwaters may change under steady flow conditions and these community changes may be beneficial or detrimental to native fishes. It is likely that steady flows will cause an increase in backwater invertebrate populations in response to warmer temperatures and a lack of flushing. We have already seen an increase in zooplankton under the current interim flow regime as compared to a peaking power flow regime (AGFD unpublished). This would further improve backwaters as feeding areas for juvenile fishes. Although it was not examined in this study, the short duration of these flows was probably not long enough for significant changes to occur in populations of even those invertebrates with the shortest life cycles. Leibfried and Blinn (1987) reported an increase in total benthic standing crop (based on drift) in the mainchannel Colorado River under five months of steady flows as compared to fluctuating flows. It may be that until invertebrate populations increase in number, use of backwaters by fish won't increase with increasing water temperature.

Warmer water and increased food abundance should cause an increase in fish growth and survival in all native fish. Clarkson and Lupher (1993) reared humpback chub larvae in 10°C, 14°C, and 20°C water. They found that over 30 days length increased 10%, 37%, and 83%, in the respective groups and that weight increased 28%, 195% and 951%, respecively. Similar, but less dramatic, results are expected in situ.

There are, however, potential negative aspects for native fishes to long periods of steady flows. Mainchannel temperatures will increase, particularly in lower reaches of the river, and may become hospitable to exotic predators already found in Lakes Powell and Mead (and in low numbers in the Grand Canyon), reservoirs immediately upstream and downstream from Grand Canyon. These predators include striped bass (*Morone saxatilis*), walleye (*Stizostedion vitreum*), smallmouth bass (*Micropterus dolomieu*), and channel catfish (*Ictalurus punctatus*). Exotic competitors may also become a problem. Fathead minnow are already common and green sunfish (*Lepomis cyanellis*) and red shiner (*Cyprinella lutrensis*) are already found in low numbers within the system. Also, Blinn et al. (1989) found that epiphytic diatom communities from the Glen Canyon Dam tailwaters changed from large, upright forms to smaller, closely adnate forms with an increase in water temperature from 12°C to 18°C. Adnate forms of diatoms may be more difficult for fish to consume.

Backwater temperatures may rise too high, making these areas unsuitable for juvenile fishes, particularly in the lower reaches of the Grand Canyon and/or during the late afternoon. Backwater temperatures under the current discharge regime of modified fluctuations reached as high as 26.6°C in May (AGFD unpublished). It is also possible that increased algae, phytoplankton, and plant growth may make backwaters anoxic during darkness, further reducing their suitability to fish.

Additionally, increased temperature may allow *B. acheilognathi* to expand its distribution within the Grand Canyon. This cestode is a thermophilic parasite of planktivorous cyprinid fishes. It requires copepods as an intermediate host and has been known to cause high mortality rates in fish (Hoffman and Schubert 1984). Apparently, cold temperatures in the mainstem Colorado River presently contain the reproducing population of this parasite to within the Little Colorado River drainage of the Grand Canyon where it infects humpback chub, speckled dace, and fathead minnow. Granath and Esch (1983) reported that egg maturation and hatching, coracidium motility, and growth and development of *B. acheilognathi* in western mosquitofish (*Gambusia affinis*) were maximized at temperatures of 25°C and 30°C, and depressed at 20°C. However, *G. affinis* is a warmwater species and *B. acheilognathi* may survive better in cold water in a species more tolerant of such conditions. Maximum mean water temperature in the LCR in 1993 was 22.4°C, with a maximum recorded temperature of 26.1°C (Gorman 1994). The maximum temperature recorded in this study was 23.77°C and maximum daily mean temperature was 18.07°C, very close to that able to support this parasite. Brouder and Hoffnagle (in review) examined the distribution of *B. acheilognathi* in speckled dace and fathead minnow throughout the Grand Canyon and found infected fish to be most common in and near the LCR. However, an infected fish was found in the mainchannel as far as 214 km downstream and in Kanab Creek (132 km downstream), a likely tributary for establishment of this parasite. Currently, there is no evidence that this parasite has expanded its range in Grand Canyon. It is most likely that infected fish found outside of the LCR were infected in that tributary and dispersed elsewhere. However, increasing water temperatures to those preferred by humpback chub will likely increase the infection rate by *B. acheilognathi*. That, coupled with the continual displacement of fish downstream, will facilitate the expansion of its range to tributaries other than the LCR and possibly the mainchannel.

Also, mainchannel turbidity and backwater dissolved oxygen levels will likely decrease under steady flows. Sabo et al. (1991) found that high quality nursery ponds along the Mississippi River contained higher turbidity, dissolved oxygen, and conductivity than low quality nursery areas. Decreased turbidity may result in increased predation on larval and juvenile fish. However, mainchannel turbidities are probably already sufficiently low to affect the behavior of fish. Valdez et al. (1992) reported increased catches of sub-adult and adult humpback chubs in trammel nets at night and during periods of high turbidity in the Colorado River. Also, three night samples collected from backwaters during these steady flows (but were not included in the analyses) contained fish not collected during daylight samples: large numbers of juvenile humpback chub as well as some adult humpback chub, flannelmouth sucker, and common carp (*Cyprinus carpio*).

These results clearly show that water temperature will increase under a regime of steady flows during periods of warm weather but the duration of these steady flows was insufficient to determine the ultimate temperature of these backwaters. Additionally, evidence is provided that dissolved oxygen and conductivity are also affected by this flow regime and that pH changes may also be expected under longer-term steady flows. The effects of steady flow conditions on plankton and aquatic invertebrates was not tested but could be extensive. The effects of steady flows and changing river and backwater conditions on fishes is inconclusive, but could also be considerable. Therefore, it is apparent that further study is needed to assess the potential changes of long-term steady flows on larval and juvenile native fishes, their food sources, parasites, and habitat before such changes are made. These studies, both laboratory and in situ, should provide significant information on the utility of steady releases for management of native fish populations in the Colorado River, Grand Canyon.

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Table 1. Native fish species of the Colorado River, Grand Canyon.

Common Name	Scientific Name	Population Status in Grand Canyon	Legal Status	
			Federal	Arizona
Bonytail Chub	*Gila elegans*	Extirpated	Endangered	Endangered
Humpback Chub	*Gila cypha*	Locally Common	Endangered	Endangered
Roundtail Chub	*Gila robusta*	Extirpated	Category II	Threatened
Colorado Squawfish	*Ptychocheilus lucius*	Extirpated	Endangered	Endangered
Bluehead Sucker	*Catostomus discobolus*	Common	- -	- -
Flannelmouth Sucker	*Catostomus latipinnis*	Common	Category II	- -
Razorback Sucker	*Xyrauchen texanus*	Rare/Extirpated	Endangered	Endangered
Speckled Dace	*Rhinichthys osculus*	Common	- -	- -

Table 2. Location of sampling sites (river kilometer and river mile below Lee's Ferry, Colorado River), side of river (when facing downstream) type of sample collected at site (D=Discharge, F=Fish, T=Temperature, S=Sonde) and flow regime during sampling (F=Fluctuating, S=Steady).

River Kilometer	River Mile	Side	Data Collected	Flow Regime
92.9	57.7	L	F	F, S
93.7	58.2	R	F	F
93.8	58.3	R	F	F
94.6	58.8	L	F, T	F, S
95.9	59.6	L	F, T	F, S
96.9	60.2	R	F	F
97.8	60.8	L	F, T, S	F, S
*98.3	61.1	R	T, D	F, S
99.1	61.6	R	F	F
100.7	62.6	R	F	S
102.5	63.7	R	F, T	F, S
103.8	64.5	L	F	F
104.0	64.6	L	F	S
105.1	65.3	L	F	F

* Site of U.S. Geologic Survey temperature and discharge gauge in mainchannel Colorado River.

Table 3. Ranges of maximum depth (cm), length (m) and width (m) of backwaters containing temperature gauges at time of fish sampling under fluctuating and steady flow regimes in the Colorado River, Grand Canyon. Location is river kilometer downstream from Lee's Ferry.

	Fluctuating Flow			Steady Flow		
Location and Side	Maximum Depth	Maximum Length	Maximum Width	Maximum Depth	Maximum Length	Maximum Width
94.6L	32-85	52-58	6-7	124	61	6
95.9L*	61	13	2	81	19	3
97.8L	107-170	28-31	5-8	112	34	5
102.5R	70-94	10-16	7-8	70	18	10

* Only one sampled collected at 95.9L under fluctuating flows.

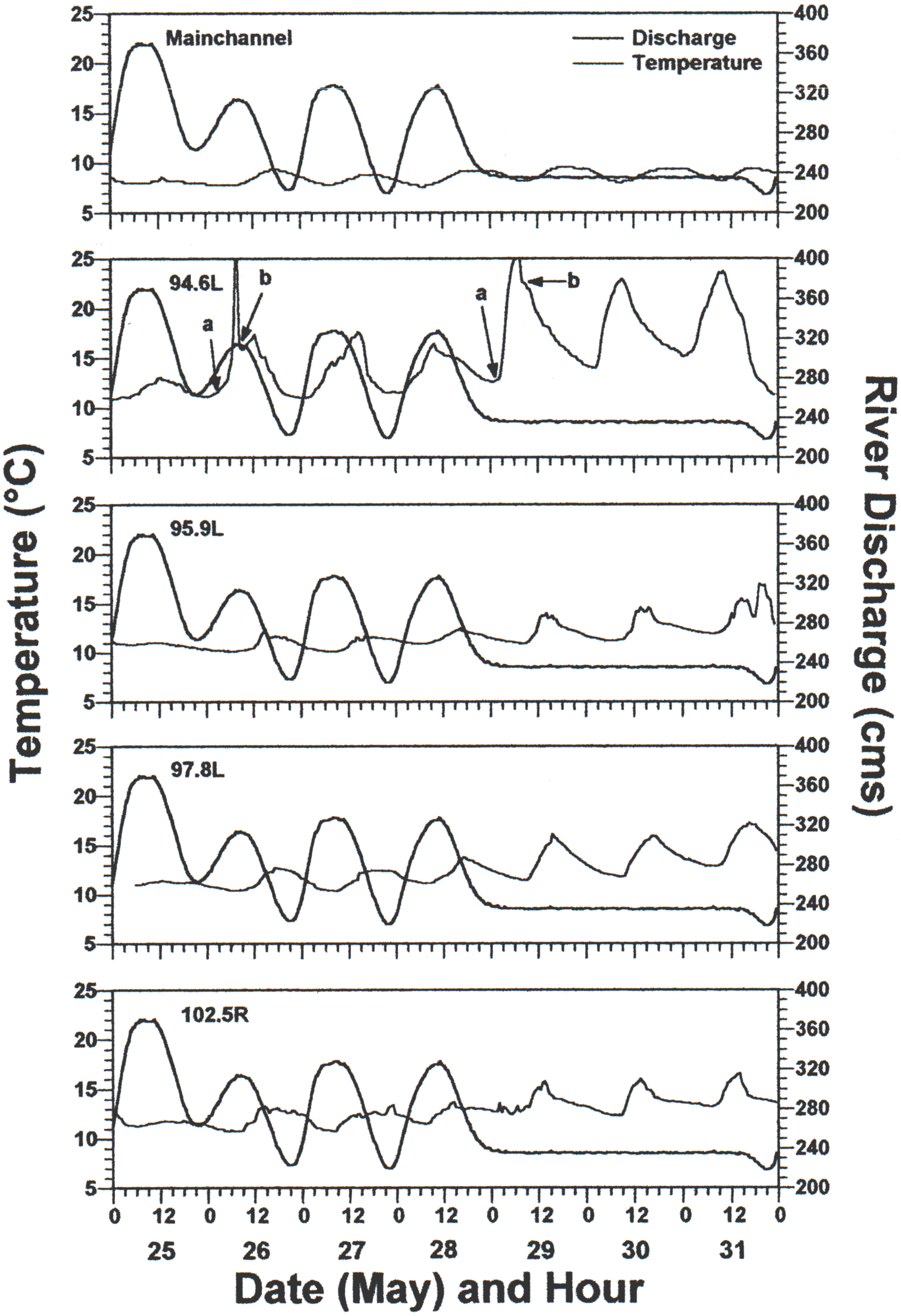

Figure 1. Changes in temperature in mainchannel (RK 98.2) and backwaters (RK 94.6L, 95.9L, 97.8L and 102.5R), and river discharge (at RK 98.2) from 25-31 May 1994 during fluctuating and steady flows in the Colorado River, Grand Canyon. Temperature gauge in backwater at 94.6L was dewatered (a) and resubmerged (b).

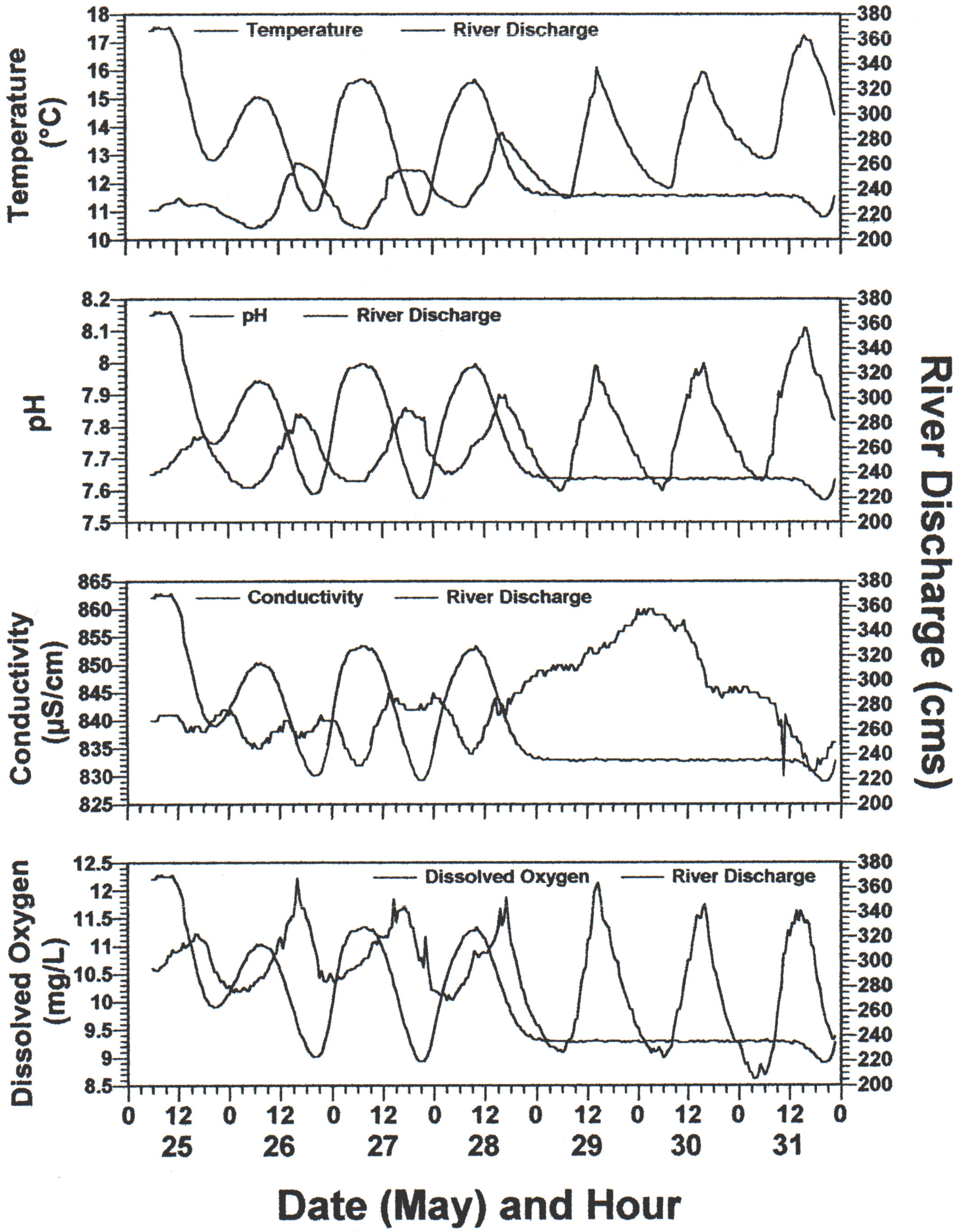

Figure 2. Changes in temperature, pH, conductivity and dissolved oxygen in backwater at RK 97.8L and river discharge (RK 98.2) from 24-31 May 1994 during fluctuating and steady flows in the Colorado River, Grand Canyon.

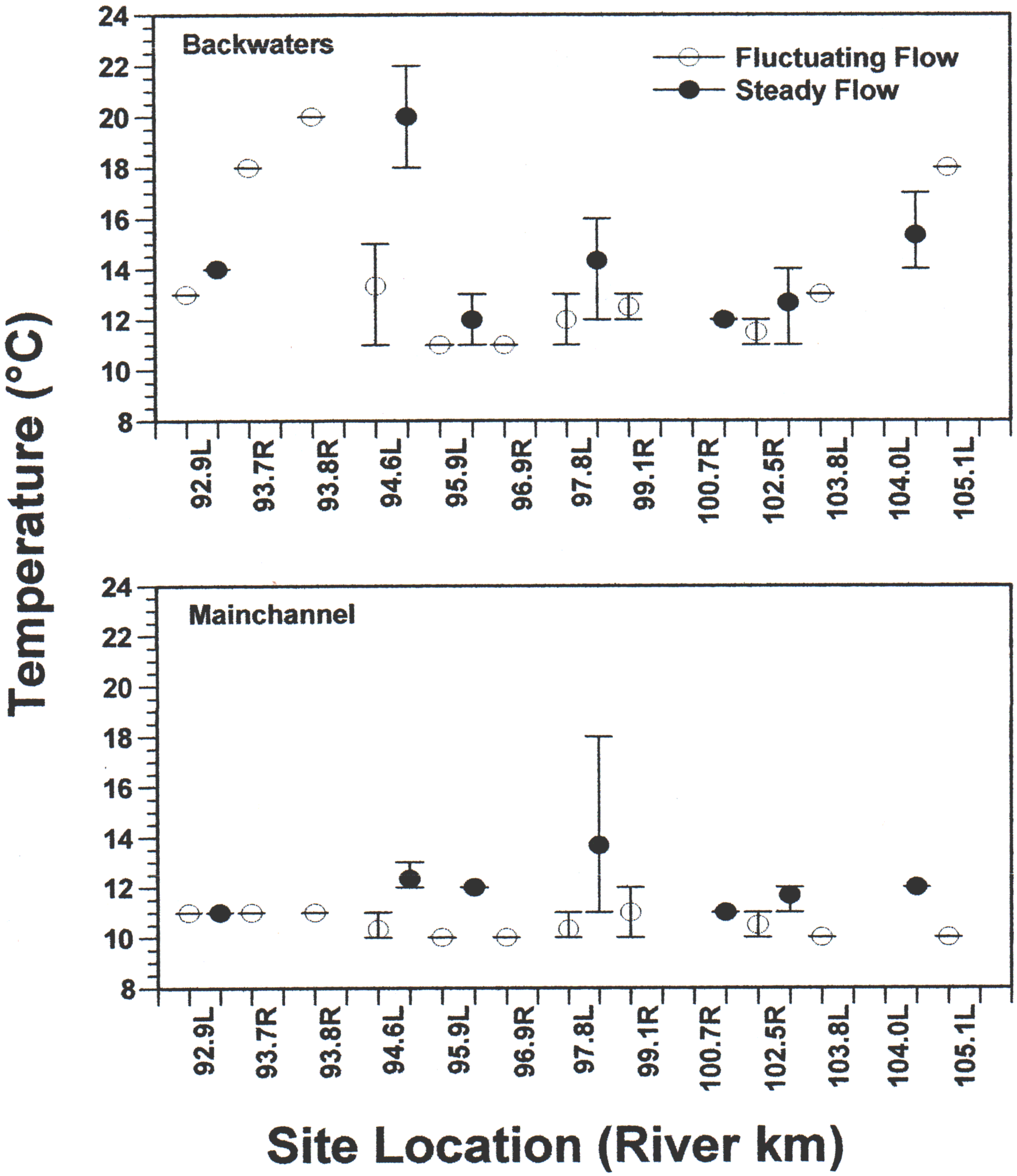

Figure 3. Mean, minimum and maximum water temperature in backwaters (top) and mainchannel beachfaces (bottom) at time of sampling under fluctuating and steady flow regimes in the Colorado River, Grand Canyon, from 25-31 May 1994.

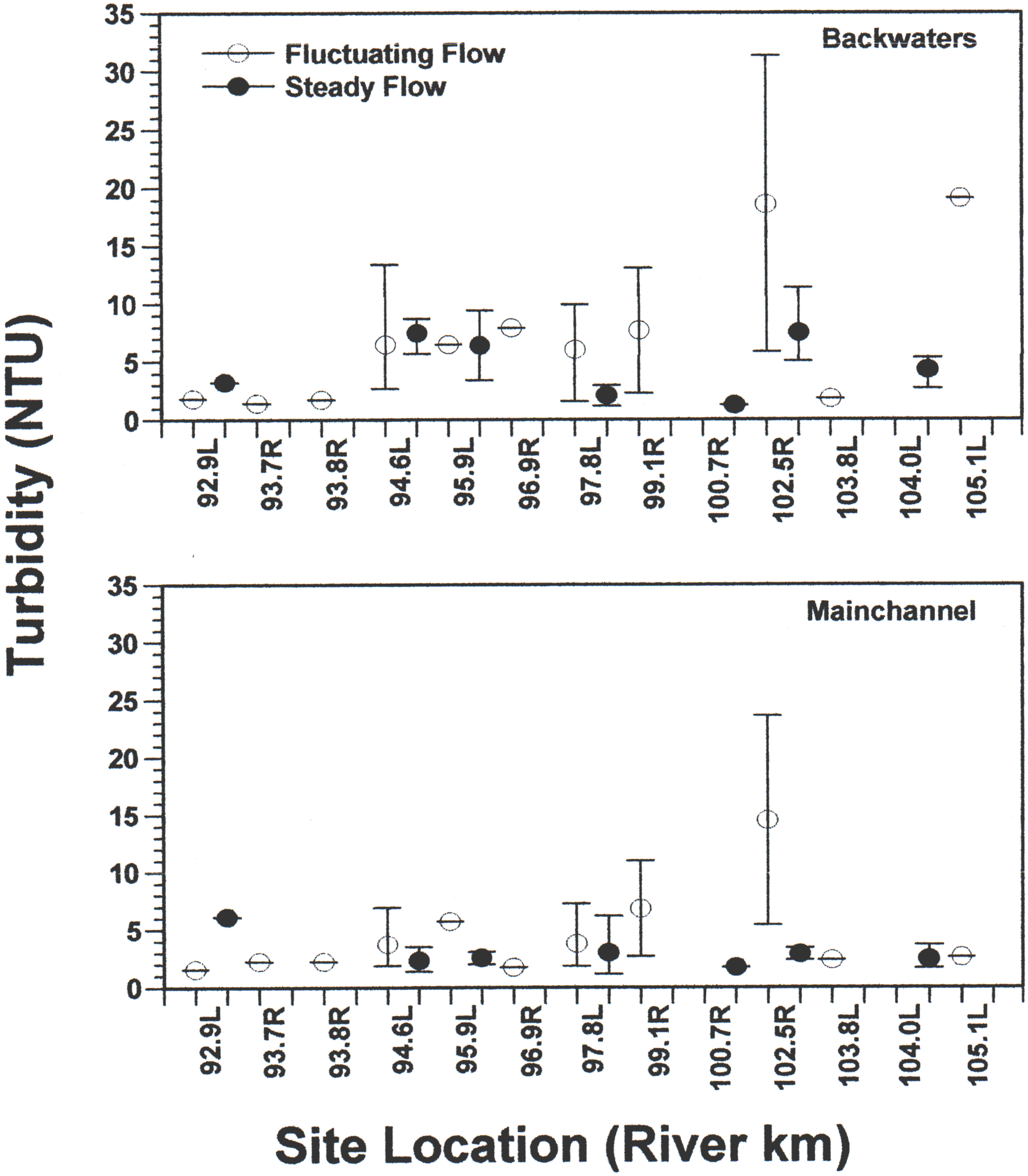

Figure 4. Mean, minimum and maximum water turbidity (NTU) in backwaters (top) and mainchannel beachfaces (bottom) at time of sampling under fluctuating and steady flow regimes in the Colorado River, Grand Canyon, from 25-31 May 1994.

Table 4. Daily minimum, maximum and mean temperature, pH, conductivity and dissolved oxygen in the mainchannel and each backwater monitored during fluctuating and steady flows in the Colorado River, Grand Canyon, from 25-31 May 1994.

Day of May	Flow Regime	Temperature °C			pH			Specific Conductance µS/cm			Dissolved Oxygen mg/L		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Mainchannel													
25	F	8.0	8.6	8.14	.	.	.	.	.	.	.	.	.
26	F	7.8	9.4	8.47	.	.	.	.	.	.	.	.	.
27	F	7.8	8.8	8.38	.	.	.	.	.	.	.	.	.
28	F	7.6	9.2	8.46	.	.	.	.	.	.	.	.	.
29	S	8.2	9.6	8.96	.	.	.	.	.	.	.	.	.
30	S	8.0	9.4	8.85	.	.	.	.	.	.	.	.	.
31	S	8.2	9.4	8.94	.	.	.	.	.	.	.	.	.
RK 94.6L													
25	F	10.82	13.10	11.831	.	.	.	.	.	.	.	.	.
26	F	11.11	17.44	13.472	.	.	.	.	.	.	.	.	.
27	F	11.02	17.66	13.556	.	.	.	.	.	.	.	.	.
28	F	11.50	16.45	13.958	.	.	.	.	.	.	.	.	.
29	S	12.60	22.88	17.305	.	.	.	.	.	.	.	.	.
30	S	14.02	23.00	18.075	.	.	.	.	.	.	.	.	.
31	S	11.31	23.77	17.595	.	.	.	.	.	.	.	.	.

Table 4. cont'd.

Day of May	Flow Regime	Temperature °C			pH			Specific Conductance µS/cm			Dissolved Oxygen mg/L		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RK 95.9L													
25	F	10.34	11.31	10.832	.	.	.	.	.	.	.	.	.
26	F	10.14	12.20	10.831	.	.	.	.	.	.	.	.	.
27	F	10.14	11.80	10.869	.	.	.	.	.	.	.	.	.
28	F	10.92	12.50	11.516	.	.	.	.	.	.	.	.	.
29	S	10.92	14.02	12.045	.	.	.	.	.	.	.	.	.
30	S	11.21	14.64	12.473	.	.	.	.	.	.	.	.	.
31	S	11.90	17.00	13.577	.	.	.	.	.	.	.	.	.
RK 97.8L													
25	F	10.96	11.47	11.231	7.65	7.78	7.712	837	842	839.8	10.30	11.25	10.854
26	F	10.41	12.91	11.409	7.60	7.88	7.705	835	842	838.3	10.13	12.54	10.793
27	F	10.38	12.50	11.508	7.63	7.86	7.722	832	846	839.2	10.27	11.89	10.955
28	F	11.14	13.79	12.229	7.65	7.93	7.755	834	848	841.1	9.75	11.93	10.598
29	S	11.47	16.11	13.263	7.60	8.00	7.767	848	859	851.7	9.08	12.22	10.194
30	S	11.83	16.06	13.653	7.60	8.01	7.780	844	860	853.7	9.00	11.75	10.006
31	S	12.86	17.27	14.774	7.62	8.13	7.854	826	846	839.0	8.60	11.63	9.920

Table 4. cont'd.

Day of May	Flow Regime	Temperature °C			pH			Specific Conductance µS/cm			Dissolved Oxygen mg/L		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
RK 102.5R													
25	F	11.30	12.60	11.690	.	.	.	.	.	.	.	.	.
26	F	10.80	13.60	11.960	.	.	.	.	.	.	.	.	.
27	F	10.80	13.70	12.000	.	.	.	.	.	.	.	.	.
28	F	11.50	13.70	12.560	.	.	.	.	.	.	.	.	.
29	S	12.30	15.80	13.650	.	.	.	.	.	.	.	.	.
30	S	12.30	16.10	13.720	.	.	.	.	.	.	.	.	.
31	S	13.20	16.60	14.200	.	.	.	.	.	.	.	.	.

Table 5. Total and mean effort and total catch, catch-per-unit-effort (CPUE) and their standard deviations (SD) for each species and all fish combined under fluctuating (25-28 May 1994) and steady (29-31 May 1994) flows in backwater and mainchannel habitats in the Colorado River, Grand Canyon.

	Fluctuating Flow		Steady Flow	
Species	Backwater	Mainchannel	Backwater	Mainchannel
Total Effort (m^2)	2806	4517	3411	4680
Mean Effort (m^2)	165.1	301.1	213.2	334.3
Bluehead Sucker				
Catch	6	0	5	0
Catch SD	0.72	0.00	0.79	0.00
CPUE	0.55	0.00	0.18	0.00
CPUE SD	1.828	0.000	0.461	0.000
Flannelmouth Sucker				
Catch	11	0	7	0
Catch SD	1.25	0.00	0.73	0.00
CPUE	0.14	0.00	0.25	0.00
CPUE SD	0.337	0.000	0.476	0.000
Unidentified Suckers				
Catch	20	0	5	0
Catch SD	2.71	0.00	0.70	0.00
CPUE	1.85	0.00	0.22	0.00
CPUE SD	5.223	0.000	0.524	0.000
Humpback Chub				
Catch	103	0	17	0
Catch SD	13.82	0.00	1.81	0.00
CPUE	0.54	0.00	0.56	0.00
CPUE SD	1.028	0.000	1.043	0.000
Speckled Dace				
Catch	89	1	84	1
Catch SD	7.20	0.24	6.42	0.25
CPUE	1.66	0.04	2.17	0.01
CPUE SD	2.693	0.169	2.109	0.037

Table 5. cont'd.

Species	Fluctuating Flow		Steady Flow	
	Backwater	Mainchannel	Backwater	Mainchannel
Fathead Minnow				
Catch	524	0	246	0
Catch SD	36.40	0.00	32.84	0.00
CPUE	9.62	0.00	9.08	0.00
CPUE SD	18.230	0.000	20.814	0.000
Rainbow Trout				
Catch	6	0	4	0
Catch SD	0.56	0.00	0.58	0.00
CPUE	0.16	0.00	0.09	0.00
CPUE SD	0.267	0.000	0.206	0.000
Total Catch				
Catch	759	1	368	1
Catch SD	44.55	0.24	34.38	0.25
CPUE	14.51	0.04	12.55	0.01
CPUE SD	18.368	0.169	21.915	0.037